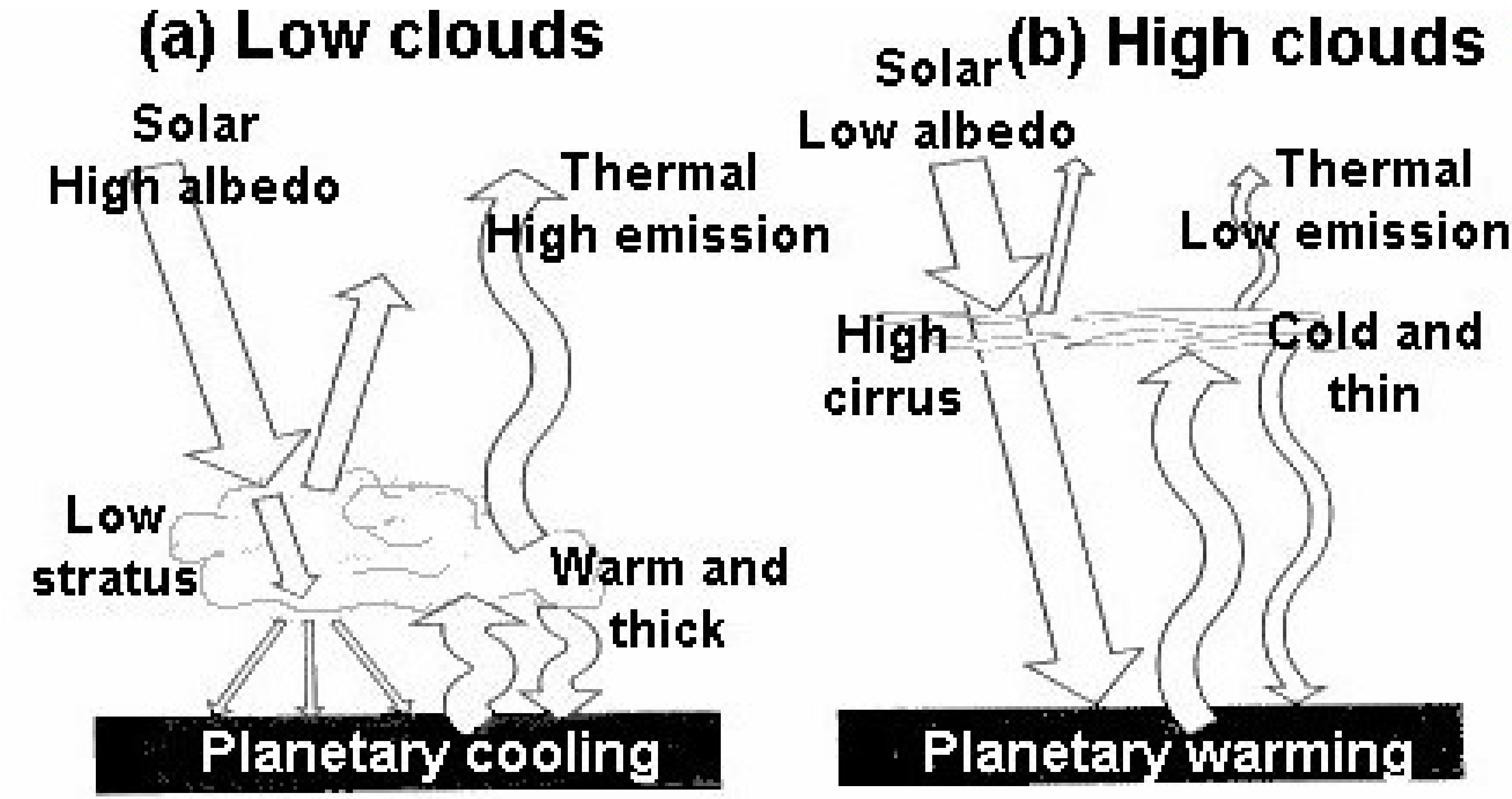
Clouds

LMDz Training – December 2016

J-B Madeleine and the LMDz team

Picture by Oleg Artemyev taken from the ISS

Radiative impact of clouds



Low clouds
- albedo effect (reflectivity of 40-50%)
- weak greenhouse effect (high temp)

High clouds :
- weak albedo effect
- strong greenhouse effect (cold clouds)

Radiative forcing

LW radiative forcing

Positive : clouds reduce the LW outgoing radiation

Annual mean : +29 W m^{-2}

SW radiative forcing

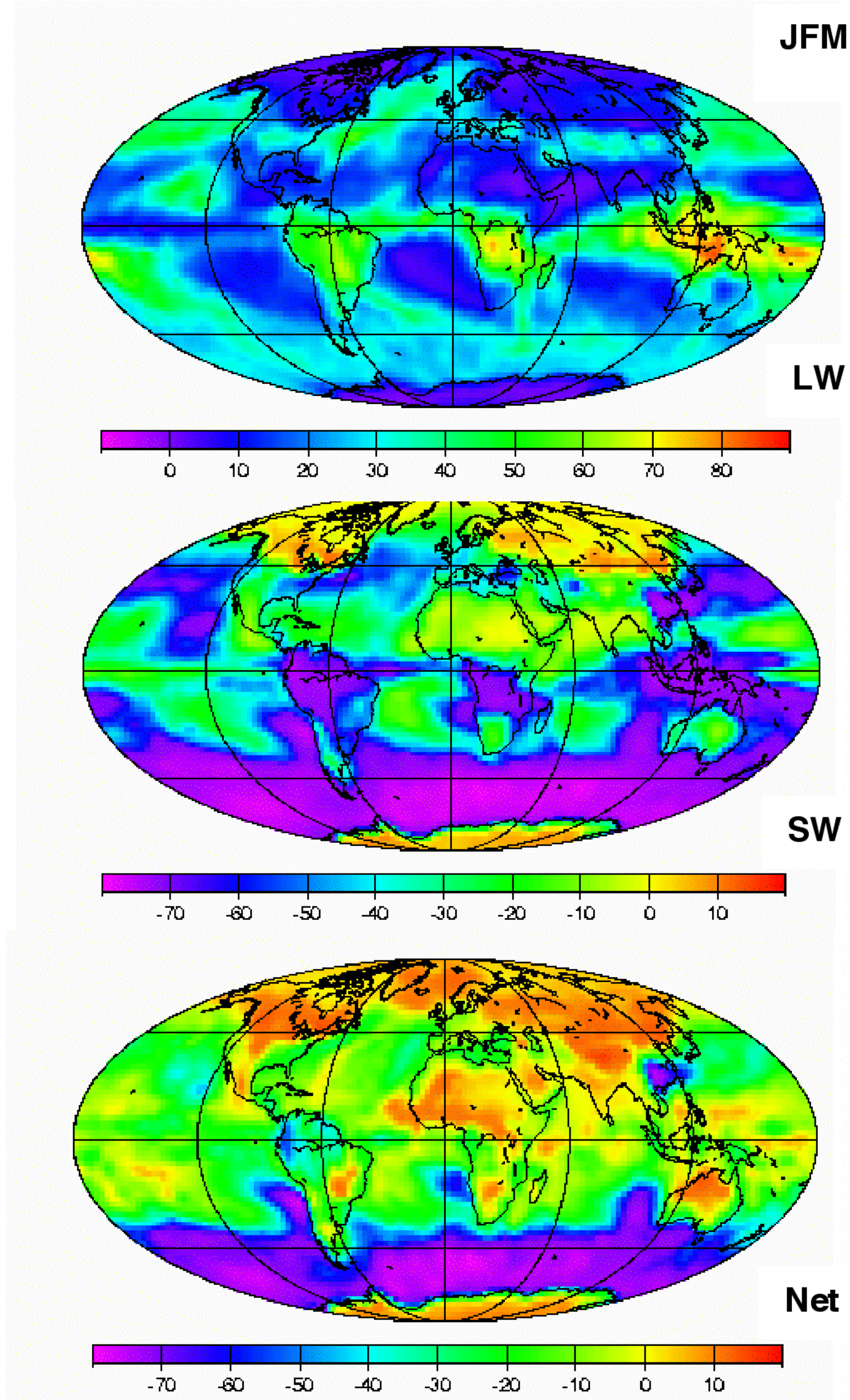
Negative : clouds reflect the incoming SW radiation

Annual mean : -47 W m^{-2}

Net forcing : **Cooling**

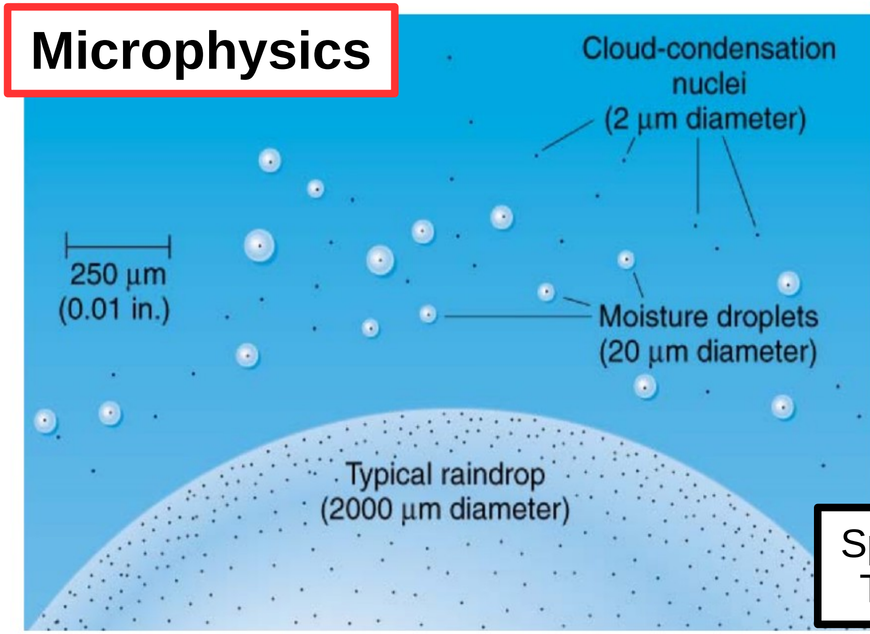
Annual mean : -18 W m^{-2}

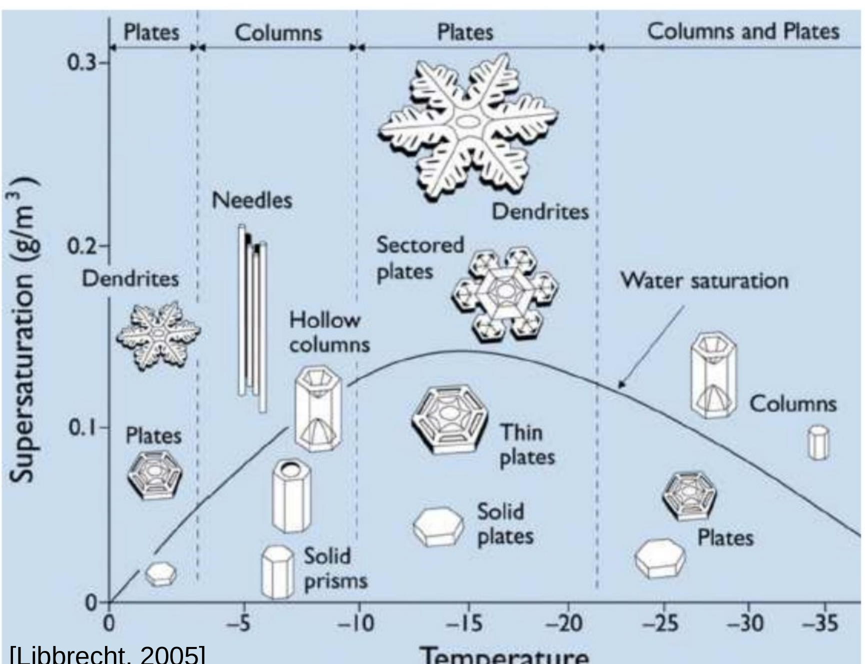
« The single largest uncertainty in determining the climate sensitivity to either natural or anthropogenic changes are clouds and their effects on radiation » IPCC report



Modeling clouds : a challenge

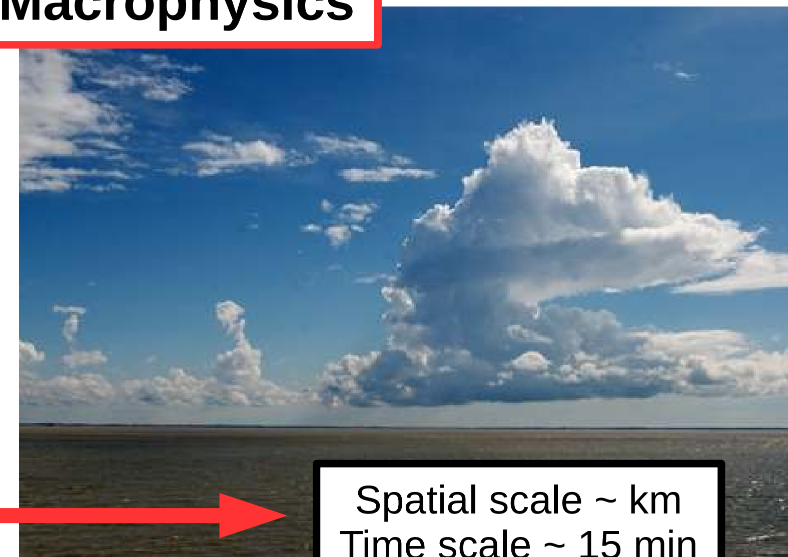
Microphysics



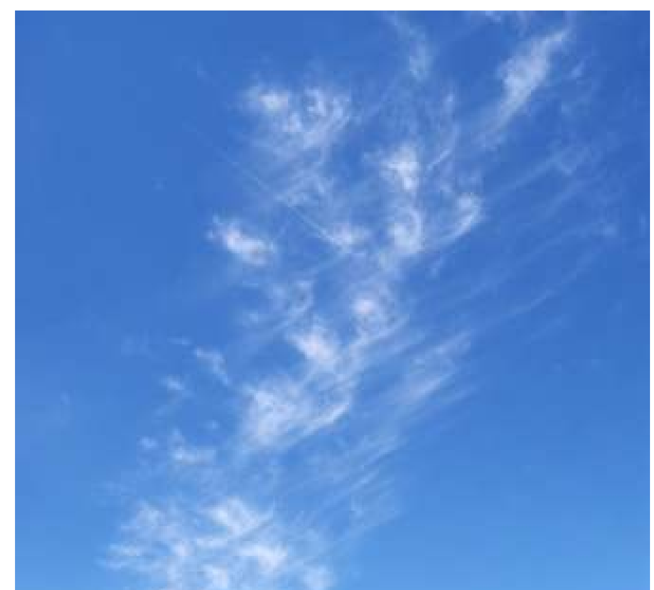


Spatial scale ~ µm
Time scale ~ 1 s

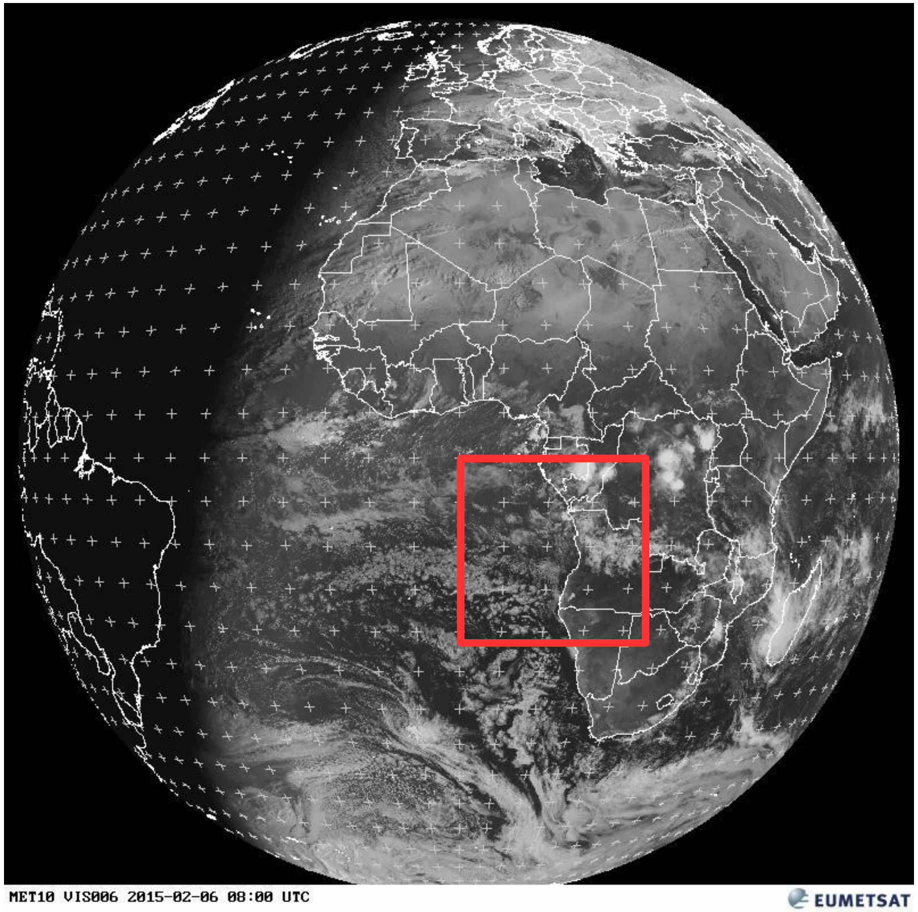
Macrophysics

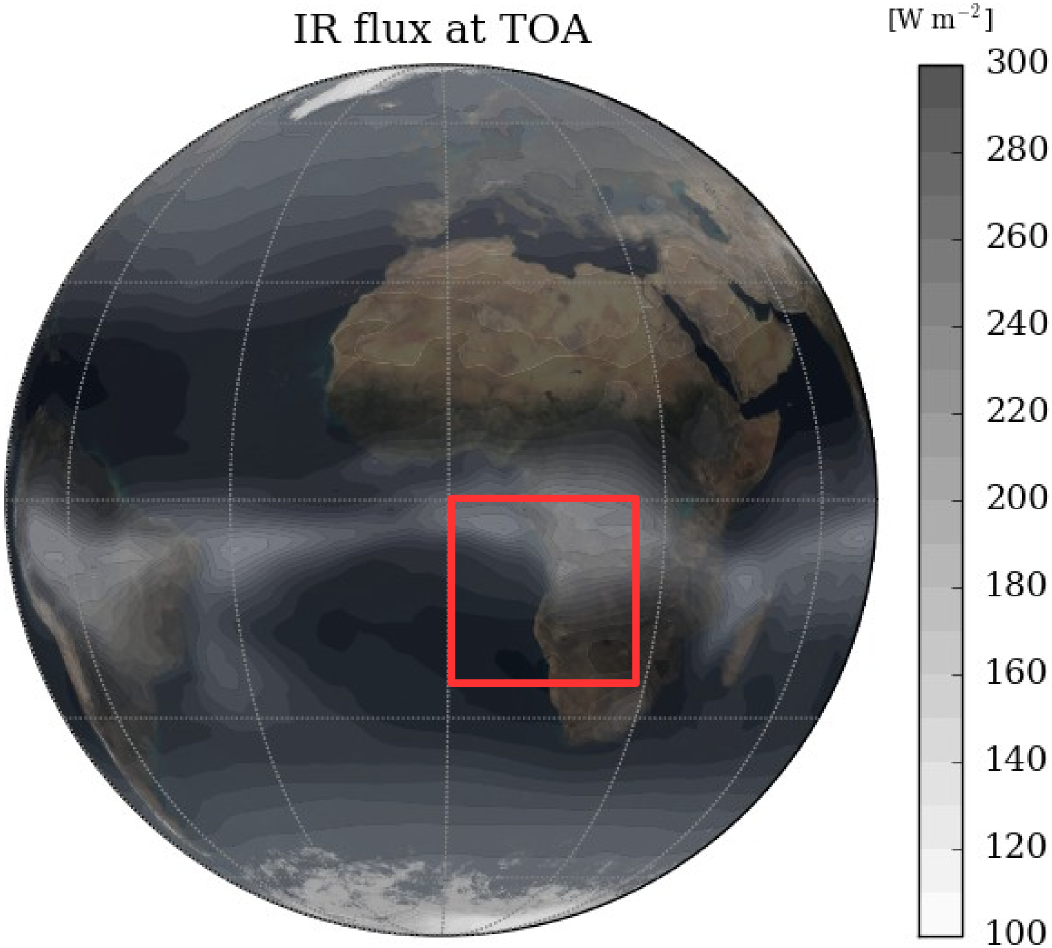


Spatial scale ~ km
Time scale ~ 15 min



A wide variety of processes





[IPSL Climate Model / Graphisme: Planetoplot]

Fundamental process

- Clausius-Clapeyron equation :

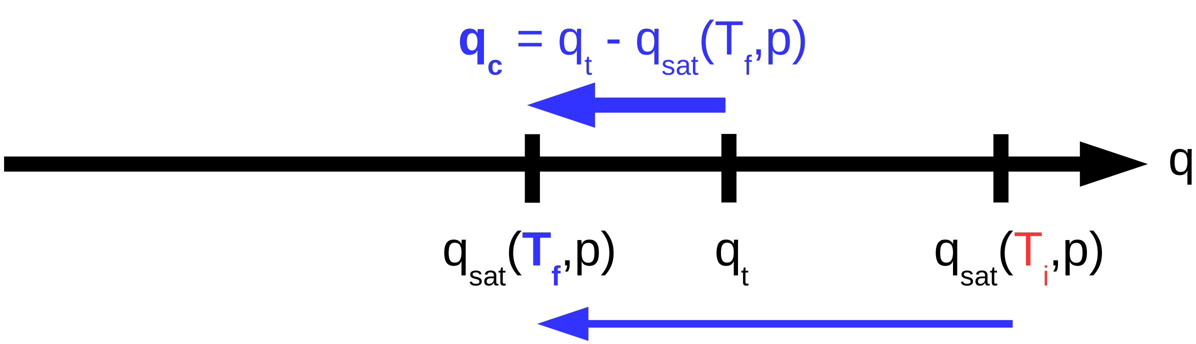
$$\frac{1}{e_{\rm sat}}\frac{{\rm d}e_{\rm sat}}{{\rm d}T} = \frac{L}{R_{\rm vap}T^2}$$

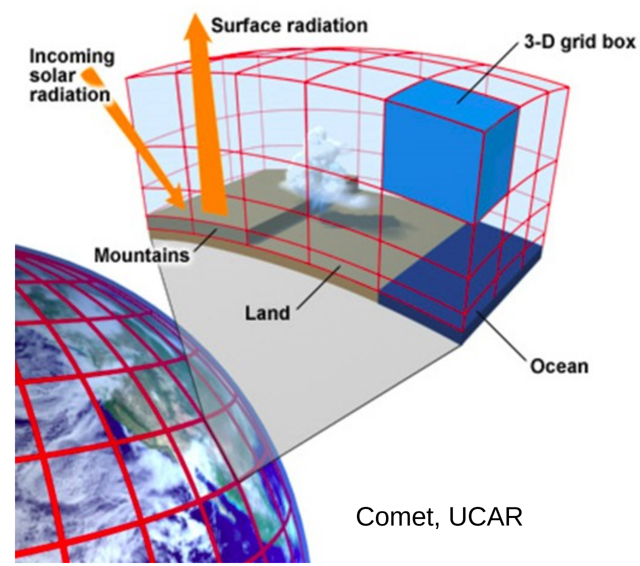
T	0°C	20°C
$e_{\rm sat}$	6.1 hPa	23.4 hPa
$q_{\rm sat}$	$3.7\ {\rm g\ kg^{-1}}$	$14.4\ {\rm g\ kg^{-1}}$

- Saturation mass mixing ratio :

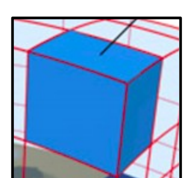
$$q_{sat}(T,p) \simeq 0.622\ \frac{e_{sat}(T)}{p}$$, where $e_{sat}(T)$ grows exponentially with temperature

- Clouds form when an air parcel is cooled :

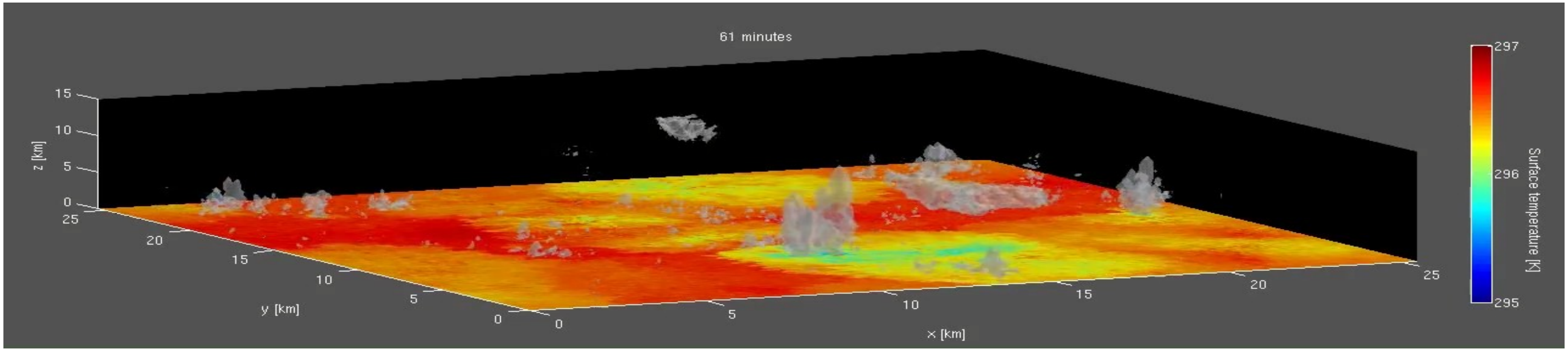




Comet, UCAR

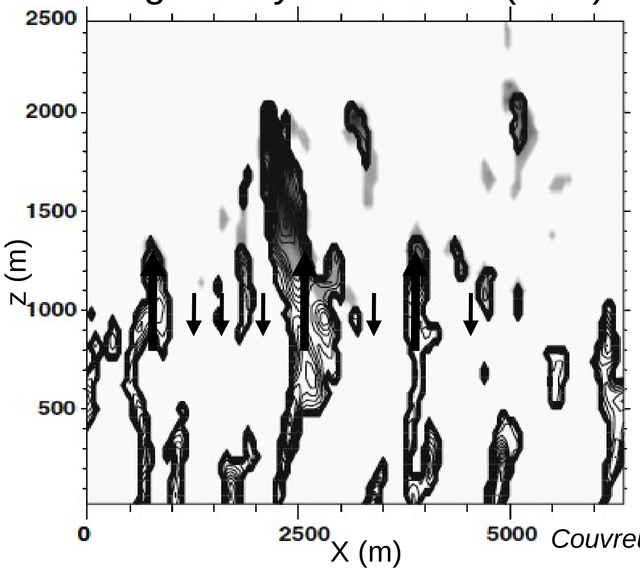
- But clouds do not look like that : 

Many processes in one grid cell



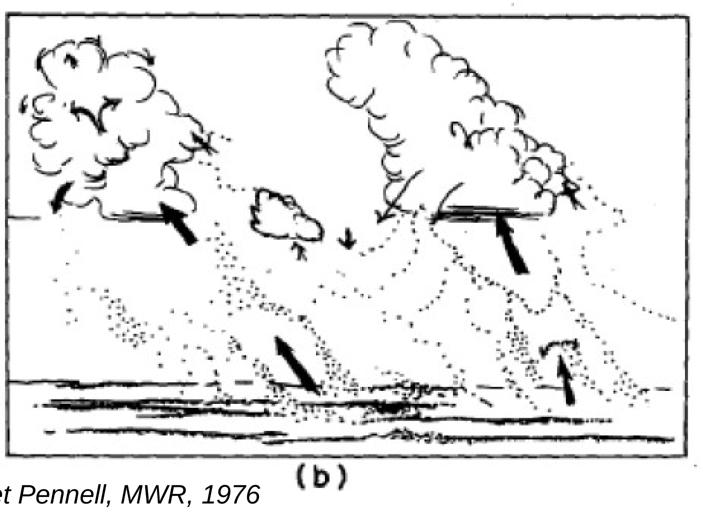
Around 8 hours of simulation by a **Cloud Resolving Model (CRM)** – C. Muller, LMD

Thermals in a
Large-Eddy Simulation (LES)



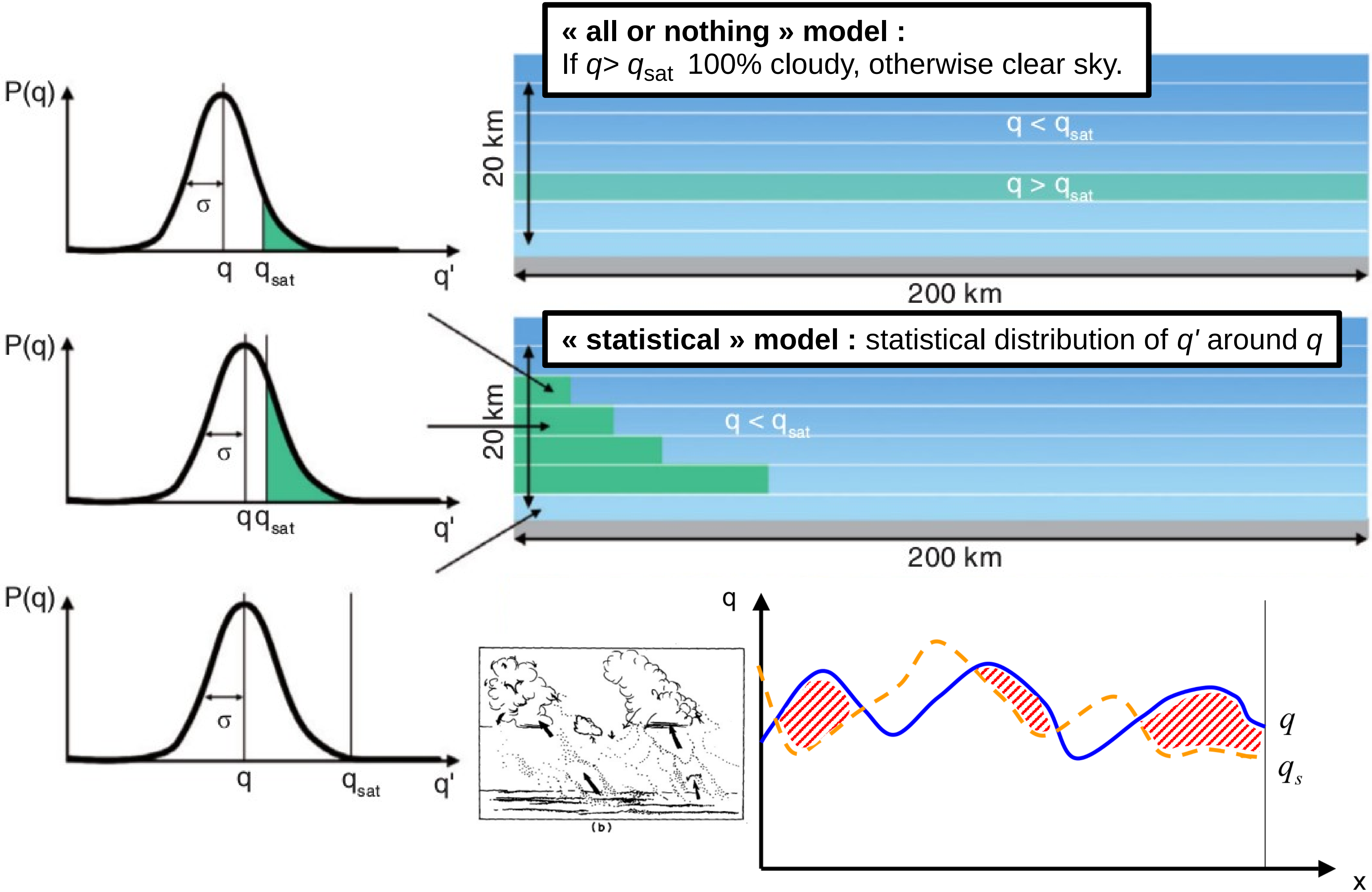
Conditional sampling of thermals based on a tracer emitted at the surface.

Couvreux et al., BLM, 2010

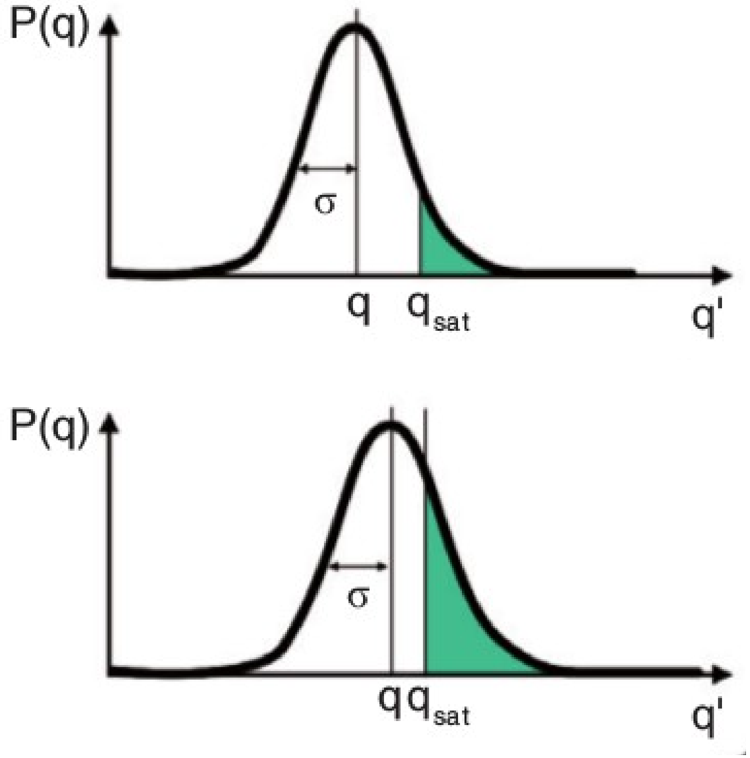


Lemone et Pennell, MWR, 1976

Statistical cloud scheme



Statistical cloud scheme 2/2



The goal of a cloud scheme is therefore to compute q_c^{in} and the cloud fraction based on the different physical parameterizations.

Mean total water content :

$$\bar{q} = \int_0^{\infty} q \ P(q) \ dq$$

Domain-averaged amount of condensate :

$$q_c = \int_{q_{sat}}^{\infty} (q - q_{sat}) P(q) dq$$

Cloud fraction :

$$\alpha_c = \int_{q_{sat}}^{\infty} P(q) dq$$

In-cloud condensed water content :

$$q_c^{in} = \frac{q_c}{\alpha_c}$$

physiq_mod.F90 structure - I

Initialization (once) : *conf_phys, phyetat0, phys_output_open*

Beginning *change_srf_frac, solarlong*

Cloud water evap. *reevap*

Vertical diffusion (turbulent mixing) *pbl_surface*

1. **Deep convection** *conflx* (Tiedtke) or *concvl* (Emanuel)

Deep convection clouds *clouds_gno*

Density currents (wakes) *calwake*

Strato-cumulus *stratocu_if*

2. **Thermal plumes** *calltherm* and *ajsec* (sec = dry)

Thermal plume clouds *calcratqs*

3. **Large scale condensation** *fisrtilp*

Diagnostic clouds for Tiedtke *diagcld1*

Aerosols *readaerosol_optic*

Cloud optical parameters *newmicro* or *nuage*

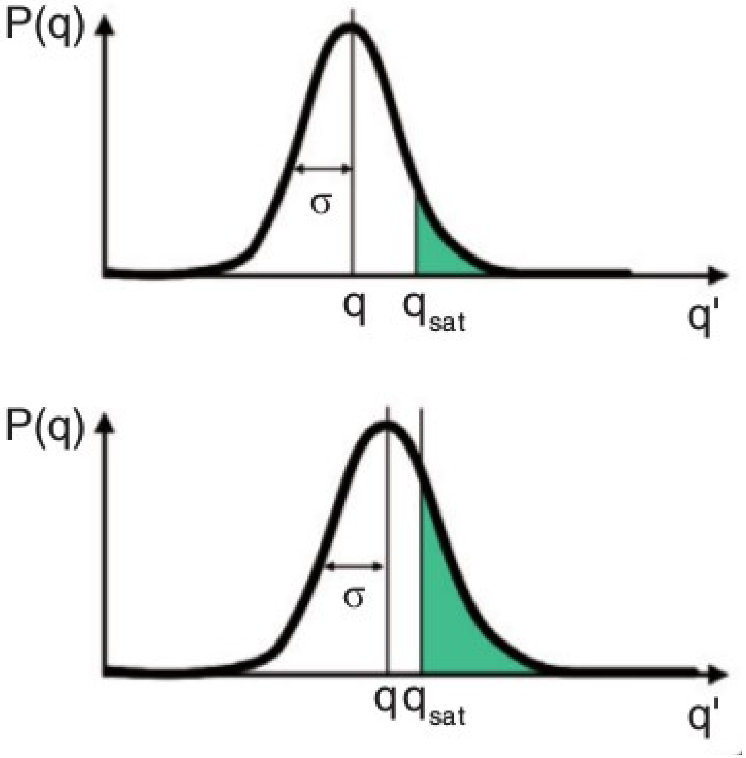
Radiative processes *radlwsw* (bis)

In blue : subroutines and instructions modifying state variables

CAREFUL : clouds are evaporated/sublimated at the beginning of each time step (~15 min), but vapor, droplets and crystals are prognostic variables. In other words, clouds can move but can't last for more than one timestep (meaning that for example, crystals can't grow over multiple timesteps).

LMDz physics parameterizations

Statistical cloud scheme 2/2



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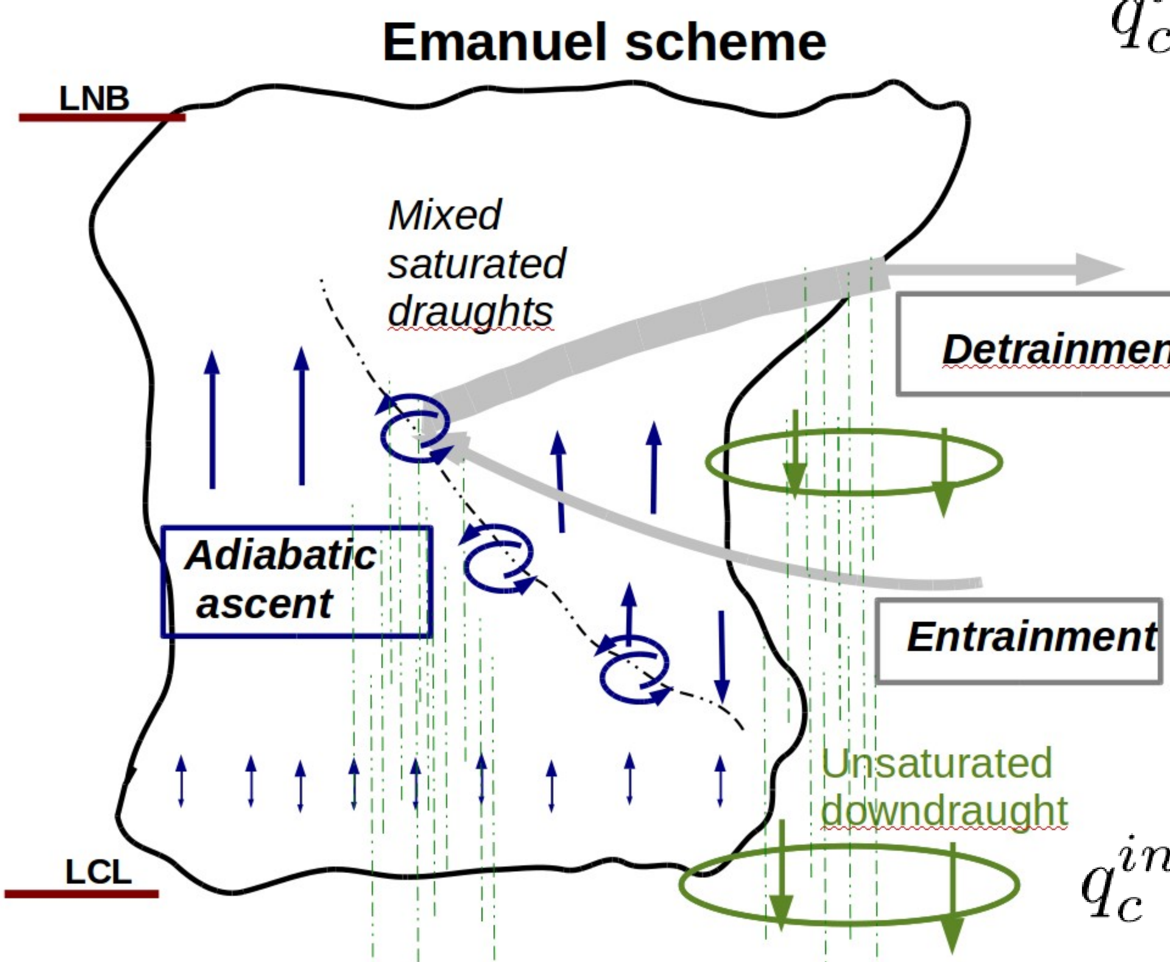
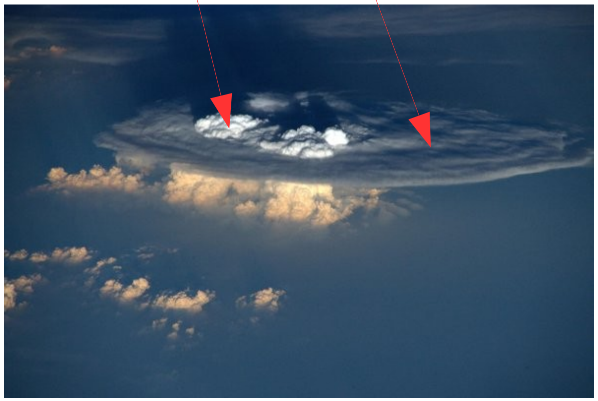
1. Deep convection



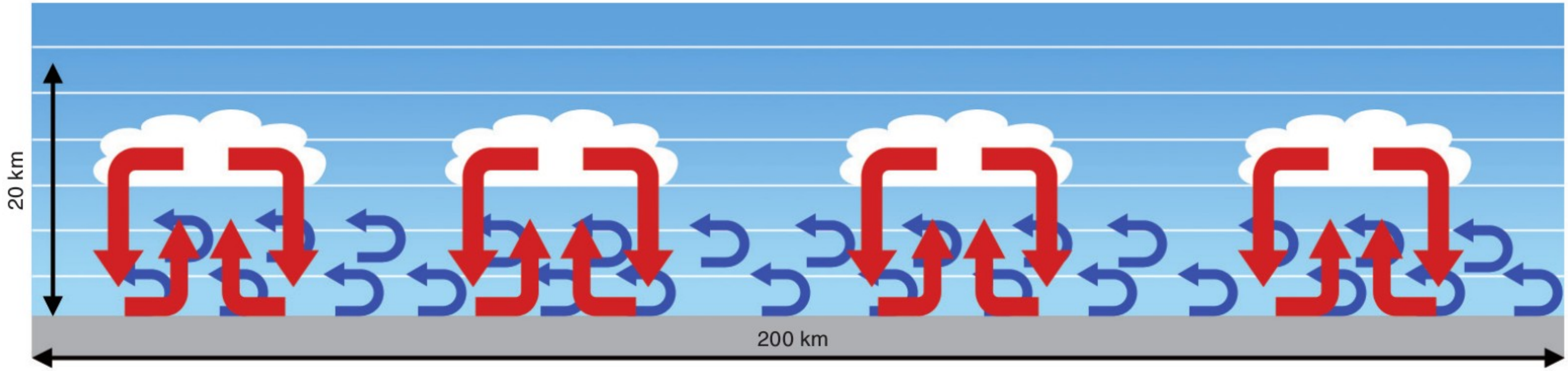
$$q_c^{in} = \frac{\sigma_a \, q_{ca} + \sigma_m \, q_{cm}}{\sigma_a + \sigma_m}$$

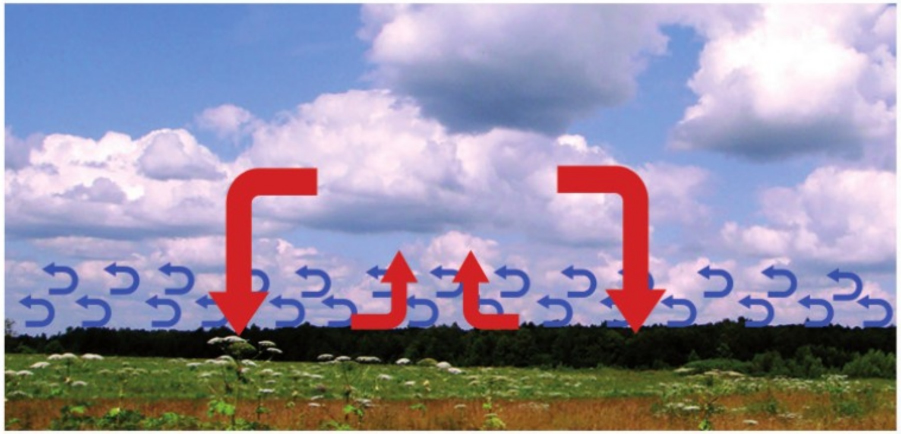


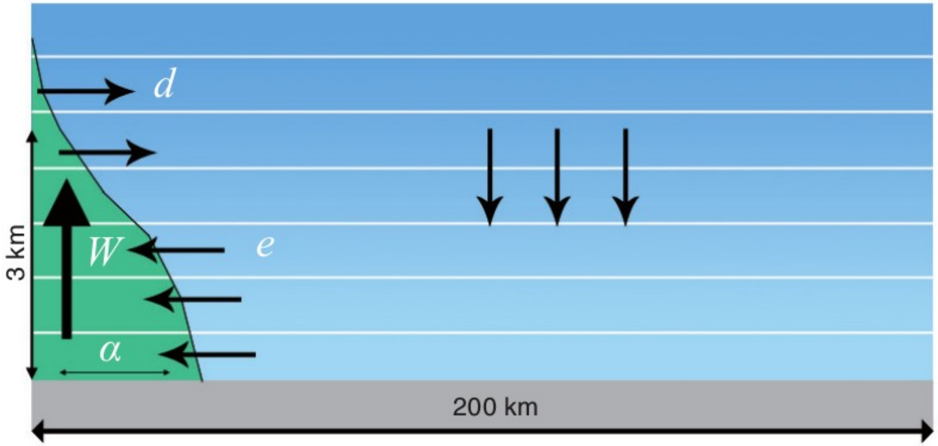
$$q_c^{in} = \frac{\frac{M_a}{\rho \, w_a} q_{ca} + \frac{\tau \, M_t \, g}{\delta p} q_{cm}}{\frac{M_a}{\rho \, w_a} + \frac{\tau \, M_t \, g}{\delta p}}$$

q_c^{in} is computed by the deep convection scheme and $\bar{q}$ is known → cloud fraction is found

2. Shallow convection 1/2







2. Shallow convection 2/2

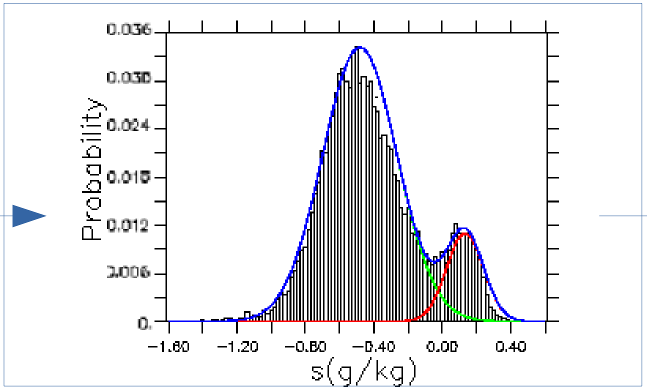
Bi-Gaussian distribution
of saturation deficit s:

$S = a_l \,(q_t - q_{sat}(T))$

- One mode associated with thermals
sth, σth
- One mode associated with their environment:
senv, σenv

s_{env}, σ_{env}
s_{th}, σ_{th}, α

Shallow convection



q_c, cf

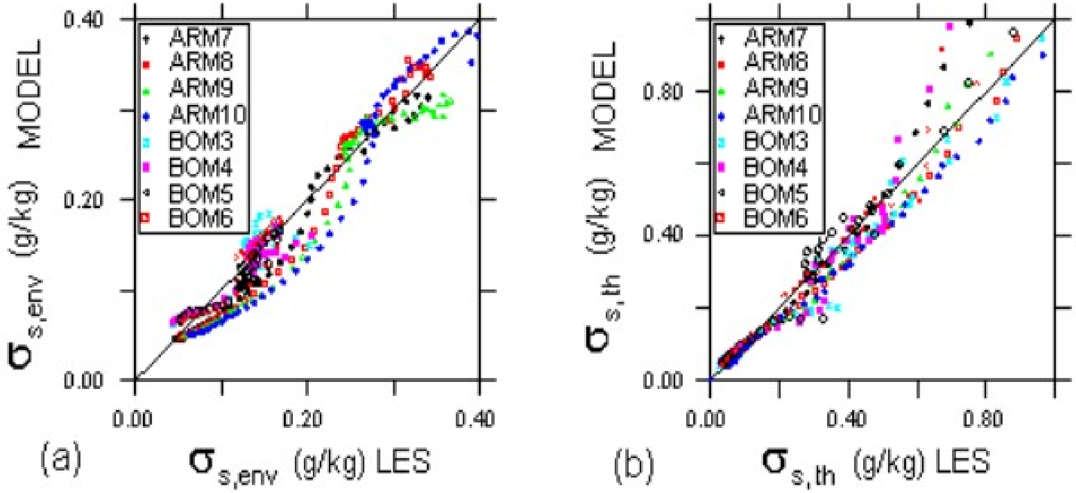
Jam & al., BLM, 2012

We know:
Mean state: s_{env}
Thermal properties: s_{th}, α

Parameterization of the variances:

$$\sigma_{s,env} = c_{env} \times \left(\frac{\alpha}{1-\alpha}\right)^{\frac{1}{2}} \times (\bar{s}_{th} - \bar{s}_{env}) + b \times \bar{q}_{t_{env}}$$

$$\sigma_{s,th} = c_{th} \times \left(\frac{\alpha}{1-\alpha}\right)^{-\frac{1}{2}} \times (\bar{s}_{th} - \bar{s}_{env}) + b \times \bar{q}_{t_{th}}$$



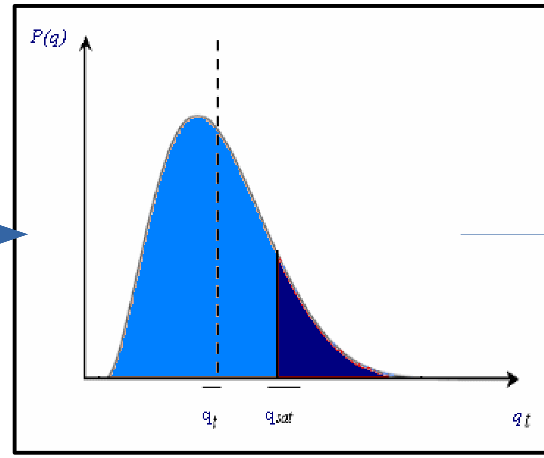
q_c^{in} is deduced from the mean water content of the environment and thermals and the parameterized spreads of the two gaussian distributions

3. Large scale condensation

Log-normal distribution of total water qt (Bony & Emanuel, JAS, 2001)

Grid-cell mean state → q, qsat

σ/q imposed →



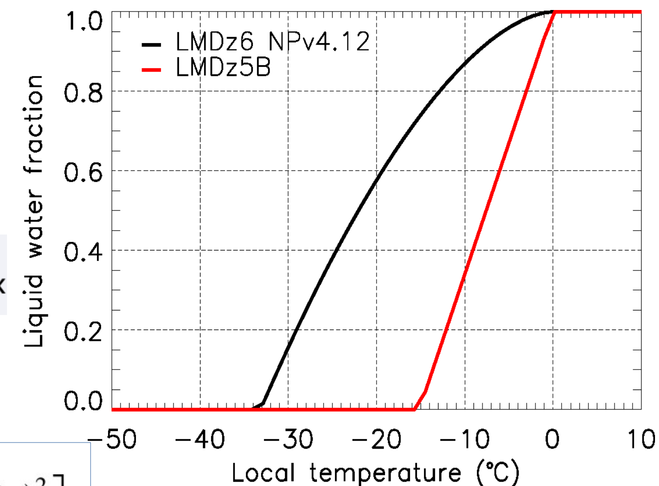
→

$$\alpha_c = \int_{q_{sat}}^{\infty} P(q)dq$$

$$q_c = \int_{q_{sat}}^{\infty} (q - q_{sat})P(q)dq$$

- condensate: liquid/ice partitioning (function of the temperature)

[a]Cloud liquid fraction $= \left(\frac{T - T_{\min}}{T_{\max} - T_{\min}}\right)^n$, for $T_{\min} \le T \le T_{\max}$



A fraction of the condensate falls as rain (parameters controlling the maximum water content of clouds and the auto-conversion rate)

$$\frac{dq_{lw}}{dt} = -\frac{q_{lw}}{\tau_{convers}}\left[1 - e^{-(q_{lw}/clw)^2}\right]$$

$$\frac{dq_{iw}}{dt} = \frac{1}{\rho}\frac{\partial}{\partial z}(\rho w_{iw} q_{iw})$$

$$w_{iw} = \gamma_{iw} w_0$$

$$w_0 = 3.29(\rho q_{iw})^{0.16}$$

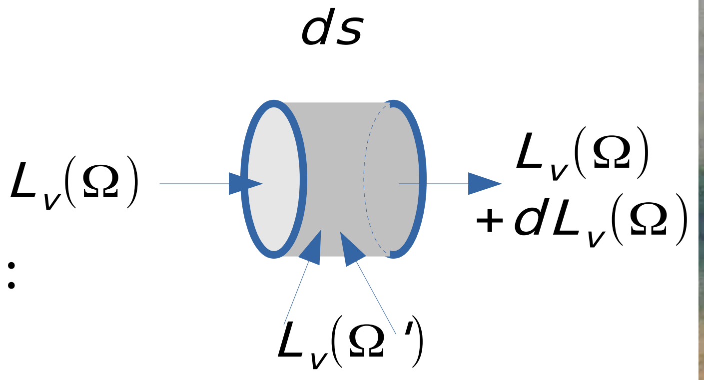
- The rain is partly evaporated in the grid below (parameter controlling the evaporation rate)

$$\frac{\partial P}{\partial z} = \beta[1 - q/q_{sat}]\sqrt{P}$$

Final cloud water content and fraction

cldfra = min(cf(thermiques) + cf (convection) + cf (grande-échelle), 1.)

cldliq = qc(thermiques) x cf(thermiques)
+ qc (convection) x cf(convection)
+ql (grande-échelle)



Transfert radiatif : des équations bien connues

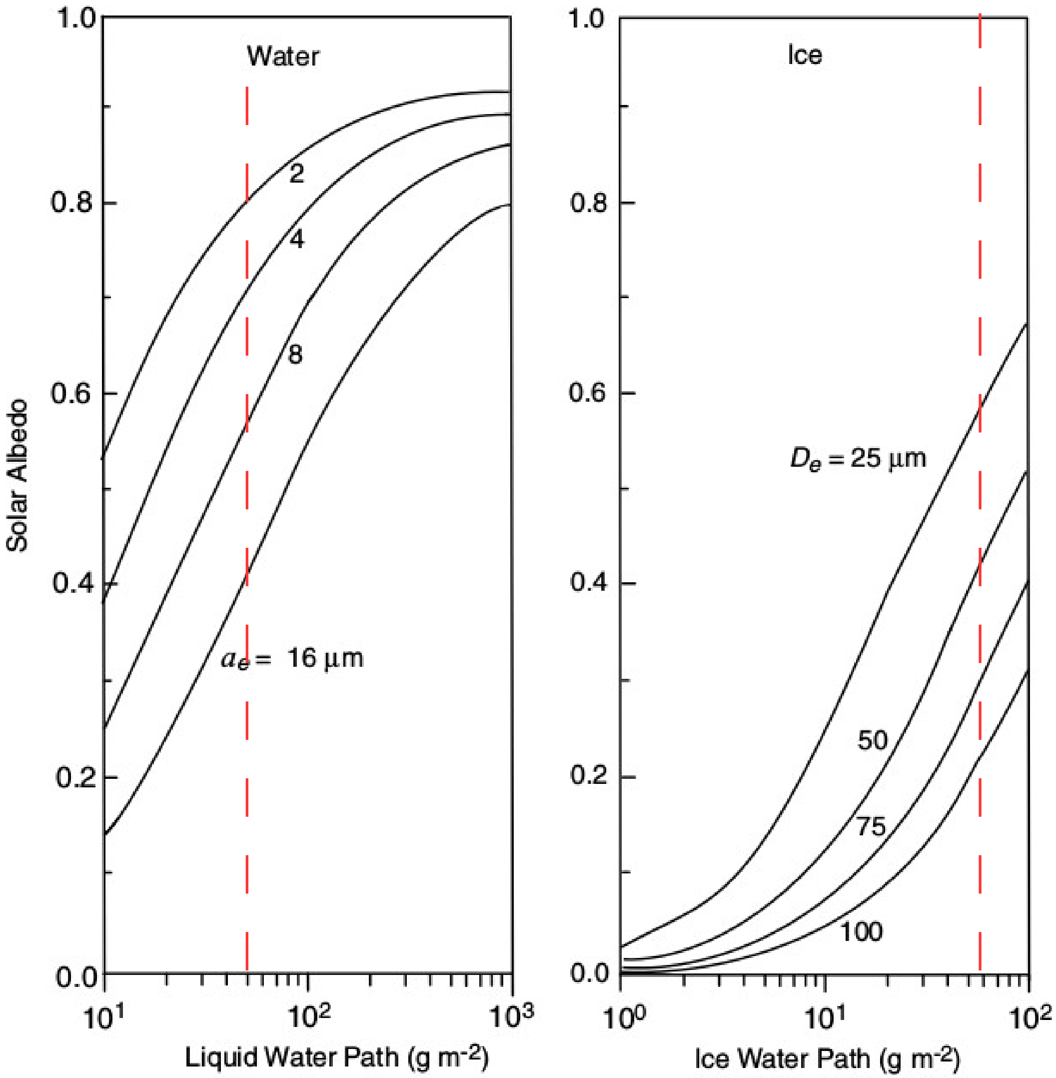
Calcul de la luminance (équation de transfert radiatif):

$$\frac{dL_v(\Omega)}{ds} = -\kappa_v L_v(\Omega) + \kappa_v B_v(T) - \sigma_v L_v(\Omega) + \sigma_v \frac{1}{4\pi} \int_{4\pi} P(\Omega', \Omega) L_v(\Omega') \, d\Omega'$$

Importance of cloud phase

Maximum random overlap

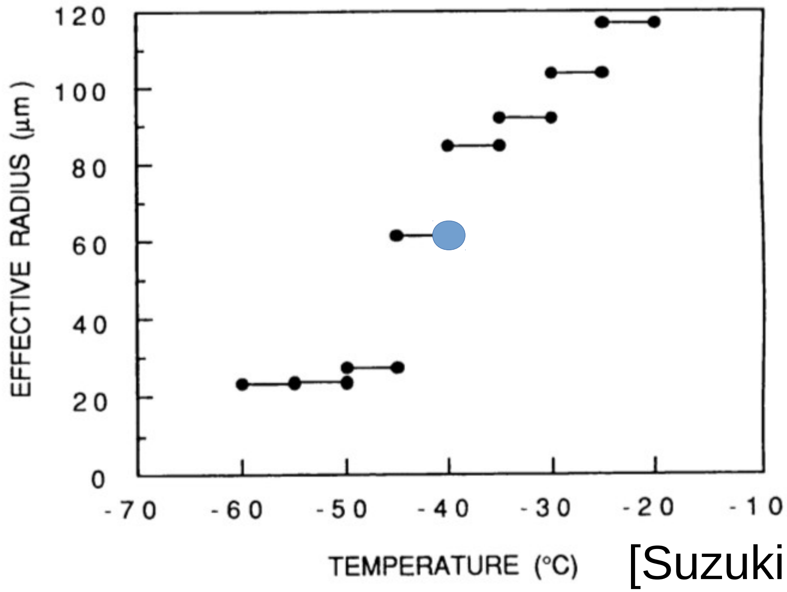
- Nuages de glace hauts tendent à **chauffer** l'atmosphère, tandis que les nuages bas **refroidissent** surface et atmosphère
- A contenu d'eau équivalent, les nuages liquides **réfléchissent plus** que les nuages solides
- Nuages liquides : si LWC augmente, réflexion domine et forçage négatif
- Nuages de glace : si IWC augmente, forçage sensible à la taille des cristaux



[Liou 2002]

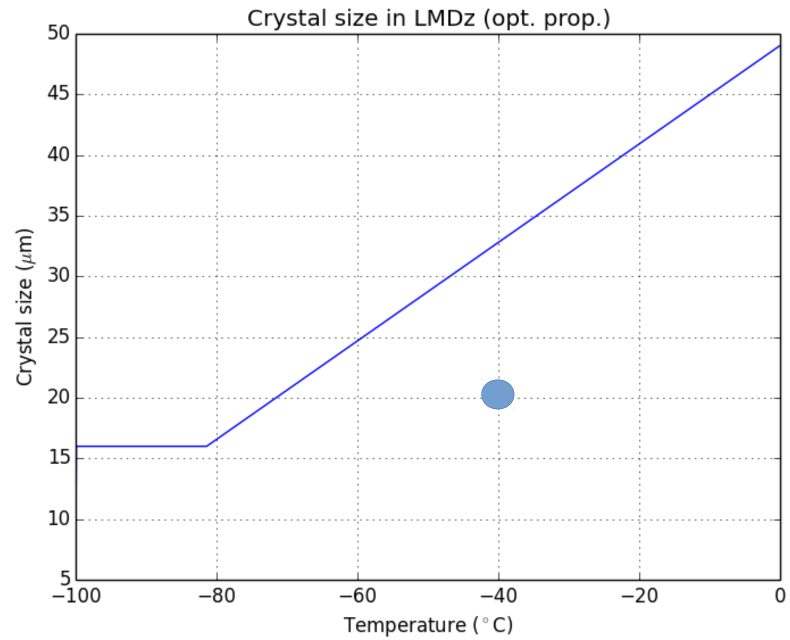
Optical properties of ice crystals

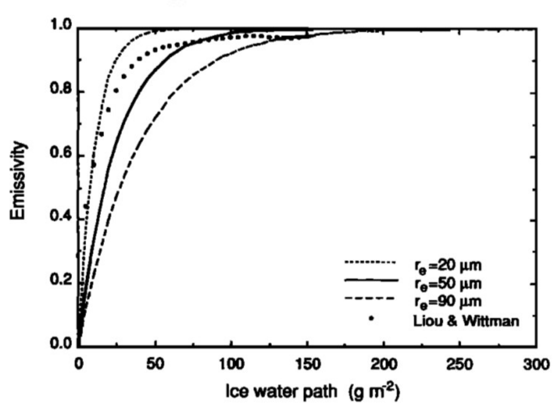
(for droplets, see O. Boucher's talk)



[Suzuki, 1993]

Fig. 2. Cloud temperature versus effective radius of cloud particle.





[Ebert, 1992]

Fig. 5. Cirrus infrared emissivity for r_e = 20, 50, and 90 μm as a function of ice water path. The solid circles represent values computed using the parameterization of *Liou and Wittman* [1979].

Droplet sizes selon r = 0.71T + 61.29 [Iacobellis et Somerville 2000] et r_{min} de 3.5 μm pour T<-81.4°C [Heymsfield et al. 1986]

What is next ?

- Better microphysics
- Ice supersaturation
- Anvils
- Radiative effect of precipitation
- RT assumptions
- Vertical heterogeneities
- Etc !